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APPARATUS AND METHOD FOR VIRTUAL PROTOTYPING OF BLOW MOLDED OBJECTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional patent application serial No. 60/441,419 filed January 21, 2003.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates generally to the design of blow molded objects and, in particular, to an apparatus and method for simulating the heating of a plastic preform.

2. Description of the Related Art:

Blow-molding operations typically involve encapsulating a heated plastic material such as a preform within the interior of a mold, applying a pressure to the interior of the preform so as to expand the preform against the mold cavity to form an article of manufacture. Issues concerning blow-molding operations involve the expansion of the material to the final desired shape. Expansion factors such as undesired thinning of certain areas of the article of manufacture

leads to further re-tooling of the mold in those critical areas to reduce the effects of the unwanted expansion and thinning. This trial and error process becomes costly as new mold and/or performs need to be designed and created. Furthermore, run times for producing prototypes of the actual article are typically costly.

To reduce trial and error and to reduce the time of design to production, computer aided design has been used for designing of the mold. U.S. Patent No. 5,458,825 describes a method for producing a prototype of a blow molded item by generating a data file of the geometry and contours for the inner cavity of a mold utilizing a computer aided design (CAD) apparatus. The data file is used to create the mold from photosensitive resin utilizing a stereolithographic apparatus. U.S. Patent No. 6,116,888 describes utilizing CAD software to design a hollow plastic container. The software model is used to generate a software model of the corresponding mold. The mold data file controls a cutting tool to machine the mold.

However, these and other software design tools fail to take into consideration a combination of factors such as temperature affects of all heating and cooling sources upon the entire preform, the stress/strain behavior of the material throughout the molding process, and the energy incident to the preform during the entire molding process.

SUMMARY OF THE INVENTION

The present invention has the advantage of simulating a heating of a plastic preform to determine one or more cross sectional thermal profiles of a final heated preform for modeling or virtually prototyping plastic containers.

A method is provided for simulating a heating of a plastic preform. A preform geometry is input into a preform design program. Oven geometry and spatial location of the preform throughout at least one oven is provided. Heating information is provided and the temperatures of the primary and secondary sources are calculated. Energy equations are solved based upon the preform geometry, the spatial location of the preform, the temperature the cooling air, and the absorption spectra of the preform material. At least one cross sectional thermal profile of a final heated preform is computed.

DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a flow diagram of the method of virtual prototyping in accordance with the present invention.

Fig. 2 is an illustration of secondary sources emitting radiation to the preform in accordance with the present invention.

Fig. 3 is an illustration of a preform transitioning along an oven showing the preform at various locations within the oven incident to heating sources.

Fig. 4 is an illustration of a preform discretized into a plurality of blocks in accordance with the present invention.

Fig. 5 is an illustration of the discretized preform incident to the direct exposure and viewing angle of the heating sources in accordance with the present invention.

Fig. 6 is an illustration of the preform discretized at critical locations indicating transitional changes to a shape of the preform in accordance with the present invention.

Fig. 7 is an illustration of the preform discretized into a plurality of intermediary sections according in accordance with the present invention.

Fig. 8 is a graph of a stress vs. axial stretch for a respective material in accordance with the present invention.

Fig. 9 is a graph of a stretch vs. blow pressure of a tube for the respective material in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

There is shown in Fig. 1 a flow diagram of the method of virtual prototyping of plastic containers in

accordance with the present invention. The method can be implemented in software run on a computer. In a first step **10**, a container (e.g., bottle) design is created by any known process thereby generating bottle geometry data. This data is entered in digitized form into a Preform Design Program **11** to generate digitized preform geometry. Inputs to the program **11** are the bottle geometry, the container and finish weight and the resin stretching characteristic. Preform designs are created so the designs may be stripped off of a core (i.e., error checking for undercuts) and positions of transition regions of the preform may be adjusted so that shoulder regions of the preform coincides with that of the bottle, if desired. A virtual prototyping module **12** receives the digitized bottle geometry in a step **13** and the digitized preform geometry in a step **14**. A Preform Heating and Blow Molding Program **15** simulates the heating and the blowing of the preform into a prototype bottle. An Oven Geometry step **16** defines the parameters of one or more ovens which parameters are input into a Calculate View and Shape Factors step **17** resulting in the spatial location of the preform through the ovens. Oven geometry parameters include lamp spacing, lamp length, lamp position, reflector position, shield position, and oven position. The spatial location is an input to a Solve Energy Equations step **18** as is the digitized preform geometry from the step **14**.

A Heating step **19** defines the parameters of the heating sources which parameters are input into a

Calculate Temperature of Primary and Secondary Heating Sources step **20**. Heating parameters include lamp wattage, lamp power settings, overall power, reflection coefficients, initial preform temperature, ceramic coating, and initial preform temperature. A heating preform module solves energy equations and computes at least one cross sectional thermal profile of a final heated preform. The temperatures from the step **20** are input into the Solve Energy Equations step **18** as are Cooling Air parameters (step **21**) and Vis/Infrared Spectra of Material parameters (step **22**). The step **18** calculates the radiation spectra to determine the energy incident upon the preform which information is input to a Compute Final Preform Temperature step **23**. To calculate the radiation spectra in step **18**, the power input to the lamps and their emission spectra is used for calculating the temperature of the lamps. One of the inputs comprises a filament enhancement factor which corrects for any lamp element shielding. Secondary sources of radiation like the temperatures of a backplate and reflectors within the oven are calculated from energy received and appropriate reflection coefficients of the back plates and reflectors, respectively. Radiation energy (E) from the heater at Temperature (T) and emissivity (ξ) to a respective area (A_p) on the preform between wavelengths λ and $\delta\lambda$ is calculated using Planck's theory of quantum statistical thermodynamics given by the equation:

$$Ej = \frac{(B_{j+1} - B_j)}{\left[e^{(\frac{14400}{T \bullet WL_j})} - 1 \right]} \bullet \frac{8950}{\left[(WL_j)^5 \right]}$$

where T is a temperature measured in degrees Kelvin

$B_{j+1} - B_j = \delta\lambda$

WL is a wavelength measured in microns

The above equation is used determine the total energy emitted for an entire range of wavelengths. The values derived from the above equation when multiplied by the emissivity of the lamps provides a real/gray body radiation output that is used as the energy incident upon the preform for absorption calculations.

The preform infrared spectra are input as absorption values for the different wavelengths in an infrared region of the electromagnetic spectrum. Also, the travel of the preform through the ovens is discretized into steps. A portion of the calculation involves determining time spent at each respective step in the oven and the exposure of the preform to each respective lamp a respective step (shown in Fig. 3). This indicates that regions closer to the lamp would have a greater amount of energy incident upon it. The inputted preform geometry is discretized (or digitized) into a plurality of small rectangular blocks having a respective volume (shown in Fig. 4). An amount of energy absorbed into each discretized block is calculated and utilized for a

temperature calculation. Also, radiation transmitted through a respective discretized block is used in calculating the energy incident and absorbed in a next adjacent discretized block. The radiation absorbed by each respective discretized block is incident to the direct exposure or viewing angle of each lamp as each respective discretized block travels through the oven (Fig. 5). Since each respective lamp will have a respective viewing angle of a respective discretized block at any given step throughout the oven, a view factor for each discretized block at any given step in the oven may be determined using the following formula:

$$V_f = (1/\pi)\int dA_p \int \mathrm{Cos}\varphi \mathrm{Cos}\theta \; dA_h/r^2$$

where A_p = Area of Preform

A_h = Area of Heater

φ = Angle between normal to preform surface and incremental area on heater

θ = Angle between normal to heater surface and incremental area on preform

r = distance between the heater surface to the preform surface (A_p to A_h)

The temperature of each discretized block of the preform is calculated by solving a second order differential heat transfer equation involving an energy balance which accounts for radiation energy input thermal conductivity of the material of the preform as a means

for transmitting the energy axially and radially. Furthermore, other factors accounted for are any boundary effects of cooling convective air current on an outer surface of the preform as well as a relatively insulated inner surface of the preform. The computation is repetitiously performed until energy balance is achieved.

In the preferred embodiment, the second order heat transfer differential equation is represented by the following formula:

$$k*\frac{d^2}{dr^2}T+\frac{k}{r}*\frac{d}{dr}T+\frac{Q}{A}=\rho*C*\frac{d}{d\tau}T \quad \textit{Units of Cal / cc * s}$$

where A= $2\pi r\Delta r$ (i.e., an area of incremental ring at radius r and thickness Δr), Q represents an energy generation term (i.e., energy per second per cm of preform sidewall thickness), τ is representative of time, ρ represents the density of the plastic, and k is the thermal conductivity of the plastic.

The thermal conductivity constant (k) is represented by CD and ρC is represented by HCD (Cal/cc*K). The heat capacity (HCD) is a function of temperature. By substituting these terms in the above equation, the formula becomes:

$$CD*\frac{d^2}{dr^2}T+\frac{CD}{r}*\frac{d}{dr}T+\frac{Q}{A}=HCD(T)*\frac{d}{d\tau}T$$

which is subject to the following boundary conditions for the inside and outside surfaces of the preform which are exposed to air. The boundary conditions are represented by the following formulas:

$$-\left(\frac{d}{dx}T)\right)*k = h*(T - T\alpha),$$

which leads to

$$\left(\frac{-k(T_i - T_{i-1})}{\Delta x}\right) = h*(T_i - T\alpha),$$

which leads to

$$T_i = \frac{\left(T_{i-1} + h*\frac{\Delta x}{k}*T\alpha\right)}{1 + h*\frac{\Delta x}{k}},$$

where T_i is a wall temperature of the preform, h is a heat transfer coefficient, and $T\alpha$ is the air temperature. The heat transfer coefficients for inside and outside preform surfaces are computed based on empirically derived relationships of air velocity.

In the preferred embodiment, the calculated thermal profile of each cross sectional area of the final heated preform is input into a blow-molding module used to determine the stress/strain behavior of the material and simulate stretching of the heated preform. In other preferred embodiments, the calculated thermal profiles

may be used for other types of modeling such as finite element analysis.

The heated preform is then blown into a container in a Simulate Stretch Blow Molding step **24** based upon the bottle geometry from the step **13**, the preform temperature information from the step **23** and data from a Stress/Strain Behavior of Material step **25**. The simulated blow molding proceeds to a Bottle Wall Thickness Profile step **26** where the thickness of each section of the prototype bottle is determined. The thickness profile can be used in a Calculate Barrier Properties step **27**. In simulating steps **24-27**, the bottle geometry is input into the model by defining heights, diameters, and radii of curvature at critical locations of the bottle. These areas of critical locations are defining points where transitional changes to a shape of the bottle are occurring (shown in Fig. 6). The intermediary sections are discretized into a plurality of sections (shown in Fig. 7) automatically by the computer program. Alternatively, the intermediary sections may be entered into the computer program. To determine how strain hardening occurs and to what extent, the model considers the effect of stretching rate, extent of uni-axial and bi-axial stretching, preform temperature and resin i.v. (i.e., intrinsic viscosity of resin) at each critical location or at each section. A relative stiffness factor is assigned to each section of the preform based on temperature and thickness. When applying a pressure or stress, the model determines which

respective section will stretch and to what extent each respective section will stretch based upon a stress-strain curve of a respective material at a given temperature as it intersects an induced blowing temperature. As a result, an axial and hoop (diameter) orientation is computed for each respective section of the preform as the preform is blown into a bottle and the resultant thickness thereof. A graph of the stress-stretch curves (i.e., for axial stretch) and stretch-blow pressure curves (i.e., for hoop stretch) for a respective material are shown in Fig. 8 and 9, respectively.

A design optimization module is used to optimize a material distribution efficiency of the preform. A Preform Design Optimization Routine 28 can be used to optimize the preform geometry. The thickness profile from the step 26 is input to a Calculate Material Distribution Efficiency (MDE) step 29. The result of the step 29 is input to a Revise Preform Geometry to Maximize MDE step 30. The revised geometry is input into the Solve Energy Equations step 18 and the blowing process is simulated again. This optimization routine 28 can be repeated until the best possible MDE is achieved.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.